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THE EFFECT OF IMMERSIVE VIRTUAL REALITY ON STUDENTS' INTEREST AND MOTIVATION IN CHEMISTRY

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Abstract. *Integrating immersive virtual reality (IVR) into chemistry education offers valuable potential to enhance student engagement through interactive visualisation. However, empirical studies regarding the effect of this new technology on students' affective factors in school chemistry, particularly in developing countries such as Indonesia, remain limited. This study aimed to explore the effect of IVR on Indonesian upper-secondary school students' interest and motivation in learning chemistry. Employing a quasi-experimental pretest and posttest non-equivalent control group design, the research involved 68 twelfth-grade students who were divided into two groups: an experimental group and a control group, with the experimental group experiencing learning through an IVR app and the control group following conventional teaching methods. The instruments included an interest in chemistry scale and a chemistry motivation scale. The data were analysed using descriptive statistics and Mann-Whitney U tests with a .05 significance level. The results revealed that while both groups demonstrated improvement in their interest and motivation scores, students in the IVR group achieved significantly higher gains. These results highlight that IVR-supported chemistry teaching is a powerful learning tool to foster twelfth-grade students' interest and motivation, offering valuable implications for integrating immersive VR into science classrooms.*

Keywords: *immersive virtual reality, upper-secondary school students, interest in chemistry, chemistry motivation*

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Introduction

In recent years, technological innovation has continued to redefine and transform the educational landscape. The integration of digital technologies has revolutionised learning environments by facilitating authentic simulations that support diverse representations and collaborative engagement (Chang, 2024; Makransky et al., 2020). This ongoing digital transformation has opened new horizons for teaching and learning, where the seamless integration between technology and pedagogy consistently generates significant educational outcomes (Alrmuny & Ku, 2025). Among various emerging technologies, Virtual Reality (VR) has garnered significant attention as an immersive three-dimensional (3D) environment capable of creating dynamic, interactive, and realistic simulated environments (Chang, 2024; Lin et al., 2021; Xiao & Hu, 2025). Once regarded as a concept restricted to science fiction or entertainment (Li et al., 2025), VR has evolved into a powerful educational innovation that enables students to experience rich sensory engagement and interactive learning (Liu et al., 2025; Yang et al., 2024). Although it originated in entertainment and gaming, VR is increasingly being adopted as a promising educational resource that provides a safe, controlled, and repeatable setting for experimentation (Li et al., 2025; Zhang et al., 2025). The potential of VR is particularly evident in science education, where immersive environments help make abstract ideas more concrete, fostering engagement and deeper understanding (Irwanto et al., 2025; Korlat et al., 2024; Xiao & Hu, 2025).

As technology continues to advance, VR is reshaping pedagogical practices and redefining how students construct knowledge (Aufenanger et al., 2025). The use of VR represents this pedagogical evolution, aligning with the learning preferences of today's digital-native students, who are accustomed to virtual interaction and exploration (Alrmuny & Ku, 2025; Xiao & Hu, 2025). By offering lifelike contexts, VR enhances the visualisa-

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tion of abstract phenomena and strengthens the comprehension of complex scientific concepts (Li et al., 2025; Yang et al., 2024). In chemistry education, in particular, VR offers the ability to overcome many of the constraints of conventional teaching by providing interactive and immersive visualisation experiences that deepen students' conceptual understanding (Hu-Au, 2024; Rahman et al., 2024). The distinctive advantages of VR, such as increasing intrinsic motivation, improving spatial reasoning, and enabling direct manipulation of 3D virtual objects (Astatke et al., 2024; Aufenanger et al., 2025; Laubscher et al., 2024), make it a valuable alternative to traditional multimedia learning tools that rely primarily on text, video, or static simulations (Alrmuny & Ku, 2025; Liu et al., 2022).

VR technology has long been promoted as an educational innovation that allows students to engage in experiences otherwise inaccessible due to limitations of space, time, and safety (Özer & Şimşek, 2025; Zhang et al., 2025). By stimulating visual, tactile, auditory, and spatial sensibilities simultaneously, VR fosters a heightened sense of spatial presence, transforming learning into a multisensory and experiential process (Christopoulos et al., 2023; Makransky et al., 2020; Xie et al., 2023). This characteristic is particularly advantageous for chemistry education, which has long struggled to bridge the gap between theoretical abstraction and practical understanding (Alrmuny & Ku, 2025). Because chemistry requires students to visualise imperceptible phenomena such as atomic structures and molecular interactions, effective visualisation and representation are critical for meaningful comprehension (Viitaharju et al., 2023). Through interactive manipulation of molecular and microscopic structures in three dimensions, VR allows students to transcend abstract representations and attain a more embodied and integrated understanding of scientific principles (Korlat et al., 2024; Makransky et al., 2020).

Chemistry remains one of the most challenging science subjects to teach and learn because it necessitates connecting macroscopic observations to microscopic explanations (Yang et al., 2024). Students' difficulties in visualising such abstract content often lead to decreased motivation and interest (Christopoulos et al., 2023; Yang et al., 2024). This problem, which is commonly encountered in Indonesia, is compounded by very limited access to laboratory experiences (Lestari et al., 2023), which reduces opportunities for experimentation and weakens the connection between theory and practice, ultimately diminishing students' engagement and performance (Hofstein & Lunetta, 2004). Conventional teaching approaches, even when complemented by multimedia slides, frequently fail to sustain students' motivation or promote deep conceptual understanding (Laubscher et al., 2024; Xie et al., 2023). Laboratory work, an integral aspect of chemistry education (Hodges et al., 2018), is often constrained by limited resources and safety concerns (Nicol et al., 2022), further impeding students' enthusiasm and learning experiences. Empirical studies indicate that virtual chemistry laboratories can effectively compensate for these limitations, providing students with repeated, safe, and cost-efficient opportunities to conduct experiments in immersive environments (Alrmuny & Ku, 2025; Zhang et al., 2025).

Within this context, integrating VR into chemistry teaching offers transformative potential to enhance student engagement through experiential learning and interactive visualisation. Previous studies have shown that immersive technologies can elevate engagement, satisfaction, motivation, and knowledge retention among students (Aufenanger et al., 2025; Chang, 2024; Xiao & Hu, 2025; Zhang et al., 2025). Despite the established theoretical advantages of VR in education, empirical evidence regarding the effect of this new technology on students' motivation in school chemistry remains limited. Most existing research has centred on higher education contexts (Jong, 2023; Matovu et al., 2024), leaving a considerable gap in understanding of the effect of VR at the secondary level, particularly in developing countries such as Indonesia. Given that upper-secondary school represents a critical stage for nurturing scientific curiosity and shaping chemistry-related professions (Ong et al., 2022), it is necessary to examine how VR influences students' learning experiences in this setting.

Interest and motivation are widely acknowledged as key determinants of students' academic engagement and success (Cheung, 2018; Costa et al., 2024). Motivated students typically demonstrate stronger academic performance and deeper conceptual understanding (Kamberi, 2025; LIbao et al., 2016). Likewise, interest plays a pivotal role in sustaining learning efforts, as students with strong situational or individual interest tend to devote greater attention and persistence to science learning (McIntyre et al., 2021). Unfortunately, numerous studies have reported a gradual decline in students' motivation and interest in science, particularly in chemistry, as they advance through school (Akram et al., 2017; Höft et al., 2019; Nikolic & Nicholls, 2018; Potvin & Hasni, 2014; Steidtmann et al., 2023). Also, Indonesian students' interest in science, as measured by PISA 2022, is substantially below the OECD average. Only 41% of Indonesian students said they enjoy learning science at school, compared to 58% across OECD countries. Furthermore, only 7% expressed a desire to pursue a career in science or technology, while the OECD average stands at 25%. Indonesian students are also

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less likely to perceive science as relevant to their future or daily life than students in many other countries (OECD, 2023). Many students perceive chemistry as overly abstract and disconnected from real life (Cardellini, 2012; Kubiatko et al., 2017), contributing to a shrinking pool of students pursuing chemistry-related studies and careers (Archer et al., 2023; Avargil et al., 2020). Given the fundamental role of chemistry in developing scientific reasoning and supporting technological innovation, addressing this motivational decline is crucial in educational contexts (Bolte et al., 2013). Thus, integrating VR into chemistry education may offer a viable pathway to stimulate students' curiosity and motivation by allowing them to explore abstract phenomena in immersive and interactive ways (Cheng et al., 2023).

Immersive virtual environments (IVR) can serve as powerful catalysts for interest and motivation, rendering learning both enjoyable and meaningful. Nevertheless, empirical evidence concerning the motivational effects of IVR among Indonesian upper-secondary school students remains scarce. Additionally, research exploring the influence of IVR on students' interest and motivation in chemistry is still limited, particularly in developing countries. Most previous studies have been conducted in developed nations (Alrmuny & Ku, 2025; Hu-Au, 2024; Li et al., 2025; Liu et al., 2022; Viitaharju et al., 2023; Yang et al., 2024), where access to advanced technology and infrastructure is more widespread. To fill these gaps, this study aims to determine the effect of IVR technology on Indonesian upper-secondary school students' interest and motivation in chemistry learning. Through immersive interaction and experiential engagement, VR is expected to cultivate enjoyment, persistence, and positive attitudes towards chemistry, ultimately supporting sustained academic motivation and interest (Liu et al., 2022; Özer & Şimşek, 2025; Xiao & Hu, 2025). This study is therefore essential not only for advancing the discourse on educational technology but also for informing the design of more engaging and effective chemistry learning practices. To achieve these aims, the study addresses the following research questions (RQs):

RQ1. How does the implementation of IVR technology influence twelfth-grade students' interest in chemistry?

RQ2. How does the implementation of IVR technology influence twelfth-grade students' motivation to learn chemistry?

Research Methodology

Design

The study employed a quantitative research approach, in which all design parameters were predetermined prior to data collection, given that the independent variable was not directly manipulable. A quasi-experimental design, specifically a pretest–posttest non-equivalent control group design, was adopted to evaluate the effects of IVR on students' interest and motivation in chemistry. This design is widely regarded as appropriate for educational technology research in school settings, as it allows the assessment of pedagogical interventions within authentic classroom environments. In the present study, complete randomisation was not feasible due to administrative and logistical constraints; thus, intact classes were maintained to preserve ecological validity while ensuring group comparability (Creswell, 2014). Through this design, the study systematically compared the outcomes of two teaching approaches (IVR-based and conventional multimedia-based teaching) to determine their effects on students' interest and motivation in chemistry learning. The educational method (IVR-based learning vs. direct teaching) served as the independent variable, while students' interest and motivation constituted the dependent variables, analysed after completion of the intervention.

Participants

This study involved 68 twelfth-grade students (18 males and 50 females) drawn from two intact classes of a public upper-secondary school located in urban Jakarta, Indonesia. Participants were selected through convenience sampling based on their availability during the 2024/2025 academic year. Such sampling, commonly employed in educational research, enables researchers to select participants who are easily accessible and reasonably representative. However, the generalisability of the findings may be limited to contexts with similar characteristics. The students, aged between 17 and 19 years (M = 17.32, SD = 0.61), were enrolled in a chemistry course that included a didactic unit on electrochemistry. Both classes followed the same curriculum,

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were taught by the same chemistry teacher, and received identical teaching content; the only variation lay in the teaching method. One class, consisting of 35 students (10 males and 25 females), was randomly designated as the experimental group (IVR group) and learned through a VR environment, while the other class of 33 students (8 males and 25 females) served as the comparison group, receiving conventional teaching using videos and PowerPoint slides. Overall, the gender distribution in the sample was 26.47% male and 73.53% female. Before the intervention, all students completed a pretest, and immediately after the intervention, they took a post-test. Although all participants were familiar with the use of information and communication technology (ICT) in classroom learning, none had prior experience with the lesson content or the use of immersive VR systems with head-mounted displays (HMDs). Participation in the study was entirely voluntary and conducted with informed consent from all students, following approval from the Institutional Review Board. A priori power analysis using G*Power 3.1 (Faul et al., 2007) indicated that a minimum of 62 participants was required to detect a large effect size ($d = .80$) based on the previous research at $\alpha = .05$ with a statistical power of .85 in a two-group comparison. The inclusion of 68 participants thus met and exceeded this requirement. Although convenience sampling may limit the generalisability of the findings, careful procedures were implemented to ensure equivalence between the two groups regarding curriculum, teacher, and demographic characteristics. This sample size also provided adequate statistical power, supporting the robustness of the study design.

Data Collection

Interest in chemistry

To examine students' interest before and after participating in the activity (answering RQ1), the interest scale developed by Boukayoua et al. (2024) was employed, with appropriate modifications to suit the specific context of this study. The questionnaire comprised 19 items encompassing four key dimensions: feeling (5 items; e.g., "I like to study chemistry at school"), value (5 items; e.g., "I really see the value of studying chemistry for my future career"), re-engagement (5 items; e.g., "When I have trouble understanding something in chemistry, I try to understand it") and knowledge (4 items; e.g., "The knowledge about electrochemistry attracts me to acquire"). The original instrument had been previously translated into and validated in Indonesian, the participants' native language. For this study, the items were further adapted to reflect the chemistry laboratory context. To ensure content coherence and contextual relevance, a panel of experts (two lecturers in chemistry education and one chemistry teacher) reviewed the adapted version. Their evaluation confirmed that the instrument appropriately measured students' interest in chemistry. Participants in two groups responded to all items using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The reliability of the scale was confirmed through Cronbach's alpha coefficients for each dimension: .87 (feeling), .91 (value), .81 (re-engagement), and .84 (knowledge), with an overall reliability of .96. These values exceeded the recommended threshold of .70 (Taber, 2018), indicating good internal consistency across the instrument. The scale was administered to both the intervention and comparison groups following the completion of the learning activities. The students took approximately 15 minutes to complete the questionnaire. The possible total scores ranged from 19 to 95, where lower values indicated lower levels of interest and higher values represented stronger interest in chemistry.

Chemistry motivation

To address RQ2, students' motivation during the learning activities was measured using an adapted version of the Science Motivation Questionnaire II (SMQ-II; Glynn et al., 2011). In this adaptation, the word "science" was replaced with "chemistry," and the questionnaire was translated into Indonesian. The adapted instrument consisted of 25 items distributed equally across five dimensions: intrinsic motivation (5 items), self-determination (5 items), career motivation (5 items), grade motivation (5 items), and self-efficacy (5 items). To validate the instrument, expert reviews were conducted by two lecturers in chemistry education and one experienced chemistry teacher to ensure accuracy, clarity, and face validity. Their evaluations ensured that the adapted version maintained conceptual alignment with the original construct and was contextually appropriate for Indonesian upper-secondary school students. The reliability analysis of the Indonesian version yielded Cronbach's α values of .87 for intrinsic motivation, .87 for career motivation, .87 for self-determination, .89 for self-efficacy, and .83 for grade motivation, with an overall α of .97, indicating a very high level of internal

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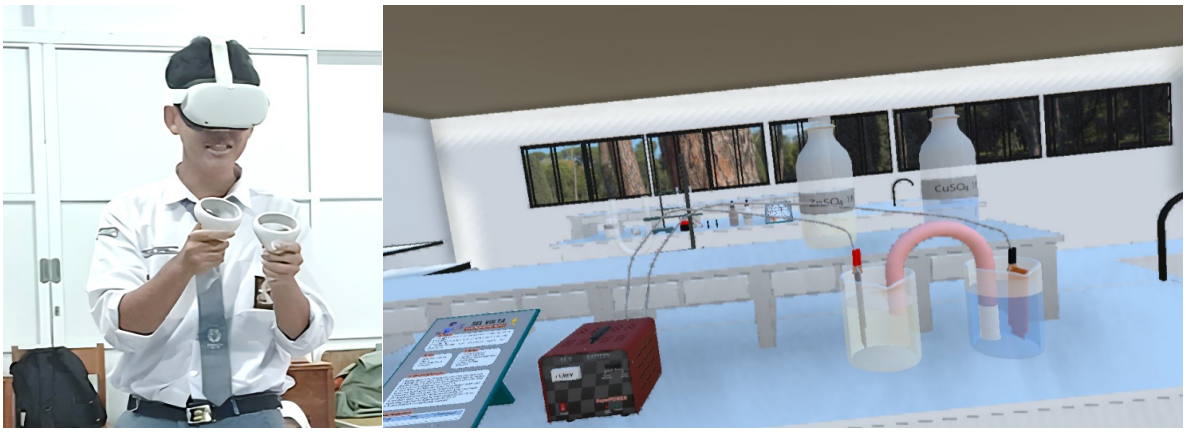
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consistency (Taber, 2018). Each item was rated on a 5-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). Students required approximately 15 minutes to complete the questionnaire. The total possible score ranged from 25 to 125, with lower scores reflecting lower levels of motivation and higher scores reflecting greater motivation towards chemistry learning.

IVR Application

The IVR application used in this study was developed through a systematic design process employing Unity 3D and Autodesk Maya software. Unity 3D served as the primary platform for designing and rendering the interactive 3D learning environment, while Autodesk Maya was utilised to create detailed laboratory objects and apparatus. The application was designed to operate with the Meta Quest 2 headset, which employs an HMD system to deliver a fully immersive experience. The teaching content of the IVR application was carefully aligned with the Indonesian upper-secondary school chemistry curriculum, focusing on the topic of electrochemistry and, specifically, voltaic and electrolytic cells. The learning intervention consisted of two virtual laboratory sessions designed to promote conceptual understanding through experiential engagement. In the first session, students explored voltaic cells and examined how electrical energy can be generated from spontaneous redox reactions. In the second session, they examined electrolytic cells to understand how external electrical energy can drive non-spontaneous chemical reactions. To simulate an authentic learning experience, the virtual laboratory environment was equipped with standard laboratory tools and safety instruments (see Figure 1). Students interacted with the virtual setting using Meta Quest motion controllers, which allowed them to select options, manipulate the apparatus, and navigate the environment intuitively. The IVR system also supported real-time observation of chemical processes and incorporated embedded instructional prompts that guided students through each experimental stage.

Figure 1
IVR Lab Application



Procedure

The session began with students completing pre-questionnaires, which took approximately 15 minutes, to assess their baseline levels of interest and motivation in chemistry. The learning intervention was then conducted under two different conditions: conventional teaching and IVR-based learning. Both groups studied the same topic (i.e., electrochemistry) within the same total duration and with equivalent content. The control group followed conventional teaching methods using printed textbooks, videos, and PowerPoint slides, while the IVR group learned using VR-based wearable devices. Each session lasted around 40 minutes, followed by a 10-minute quiz. The duration of teaching, learning objectives, and exposure to lesson content were identical across groups to ensure consistency and eliminate time-based confounding factors. Both lessons were developed from the same learning design and aligned with the official school chemistry curriculum

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mandated by the Ministry of Primary and Secondary Education of the Republic of Indonesia. Furthermore, the same teacher delivered both lessons, ensuring that teaching delivery, learning outcomes, and teaching style remained consistent across conditions. After completing the learning activity, students in both groups were asked to fill out post-questionnaires (motivation and interest scales) identical to those administered at the pretest stage. This stage took approximately 15 minutes and was carried out immediately following the learning session.

Intervention in the experimental group

Students assigned to the IVR group first received a 10-minute introductory session on how to operate the device and navigate within the IVR laboratory. During this session, the teacher explained the potential for cybersickness and advised students to immediately report any discomfort. Afterwards, the 40-minute intervention began, where the teacher introduced Meta Quest 2, comprising an HMD and two controllers, and guided students in adjusting the headset straps for a comfortable fit. Students were shown how to select, grab, and manipulate virtual objects, and they were instructed to follow the task prompts displayed on the virtual whiteboard. Figure 1 illustrates students using Meta Quest 2 during the electrochemistry experiment. Throughout the IVR intervention, students conducted two virtual electrochemistry experiments: voltaic cells and electrolytic cells. Each experiment lasted about 20 minutes on average. To facilitate collaborative learning, students were organised into groups of five, sharing one IVR set per group. Within each group, one student at a time used the HMD and controllers to perform the experiment, while others observed the activity on a shared screen. The students took turns wearing the headset so that each could experience the immersive environment. They were allowed to remove the headset and rest if they experienced dizziness or discomfort. During the activity, three research assistants provided technical support, helping troubleshoot connection issues or operational difficulties with the VR system. The teacher supervised and guided the learning process, ensuring students remained focused on the objectives of the electrochemistry lesson. After completing the VR-based experiments, students in each group engaged in face-to-face small-group discussions and worked together on a worksheet designed to consolidate their understanding of the topic.

Intervention in the control group

In contrast, students in the control group received direct teaching delivered through a PowerPoint presentation, videos, and printed materials, following a teacher-centred approach. The session began with a 10-minute introductory lecture outlining the upcoming learning activities. The teacher guided the class slide by slide, providing verbal explanations and elaborations on the concepts. As with the IVR group, control group students were divided into groups of five and studied the same content on electrochemistry. The teaching materials included PowerPoint slides, textbook-based content, and videos aligned with the school curriculum. After receiving the presentation, students collaborated within their groups to complete the same learning tasks and worksheets as those given to the IVR group. The lesson included teacher-led explanations, guided pair work, and textbook-based dialogues to ensure student participation and comprehension. No VR elements were used in this condition, and the learning experience remained within the conventional classroom environment.

Data Analysis

Descriptive and inferential statistical analyses were conducted to examine the effect of IVR on students' interest and motivation in chemistry. Means and standard deviations were computed for descriptive purposes. To ensure the validity of further analyses, several assumption tests were performed. The Kolmogorov-Smirnov and Shapiro-Wilk tests were employed to check the normality of the data, and the results indicated significant deviations from normality ($p < .05$). Since these assumptions were not satisfied, non-parametric statistical methods were employed for subsequent analyses. Specifically, Mann-Whitney *U* tests were performed to compare the average scores of the experimental and control groups before and after the intervention. This non-parametric statistical procedure is considered appropriate under such conditions because it remains reliable even when data do not follow a normal distribution and when group variances differ. All quantitative analyses were carried out using IBM SPSS Statistics version 26.

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Ethical Considerations

This research received ethical approval from the Jakarta State University Research Ethics Committee (733/UN39.14/PT.01.05/VI/2025). Before participating in the study, all students in both groups signed a consent form confirming their understanding of the study procedures and their rights. They were fully informed of the study's purpose, procedures, and voluntary nature. They were assured that withdrawal was possible at any time without negative consequences. Confidentiality and anonymity of all responses were strictly maintained throughout the study.

Research Results

Interest in Chemistry

At the beginning of the intervention, no significant difference was detected in the pretest scores between the experimental group (EG) and the control group (CG) ($p > .05$). To determine whether there was a significant treatment effect between the two groups, gain scores were calculated. Table 1 exhibits the results of the Mann-Whitney *U* test, which was performed to evaluate differences in the improvement of students' interest in chemistry between the EG and CG. As shown in Table 1, the mean difference between posttest and pretest scores (gain scores) in all sub-dimensions was consistently higher for the EG than for the CG. For the feeling sub-dimension, the EG obtained a mean difference of 0.60 ($SD = 0.31$), whereas the CG only achieved 0.13 ($SD = 0.27$). The *U* test revealed a statistically significant difference ($U = 161.50$, $Z = –5.19$, $p < .001$), indicating that students who learned with IVR experienced stronger emotional engagement with chemistry. Similarly, in the value sub-dimension, the EG demonstrated a higher mean difference ($M = 0.65$, $SD = 0.29$) compared with the CG ($M = 0.09$, $SD = 0.30$), with a significant *U* value of 108.00 ($Z = –5.84$, $p < .001$). This suggests that the use of IVR helped students perceive the learning of electrolysis as more meaningful and relevant to their lives. The re-engagement sub-dimension also showed a substantial improvement for the EG ($M = 0.62$, $SD = 0.24$) compared with the CG ($M = 0.18$, $SD = 0.25$), and the difference was statistically significant ($U = 126.00$, $Z = –5.63$, $p < .001$). This result implies that students exposed to IVR were more motivated to continue exploring chemistry topics even after the learning session. For the knowledge sub-dimension, which reflects students' curiosity and desire to deepen their understanding, the EG again outperformed the CG, with a mean difference of 0.82 ($SD = 0.36$) compared to 0.25 ($SD = 0.39$). The *U* test confirmed the significance of this difference ($U = 164.00$, $Z = –5.15$, $p < .001$). These findings reflect that the use of IVR significantly enhanced all aspects of students' interest in chemistry learning.

Table 1
Difference (Gain Scores) in Interest for the Two Groups

Dimensions	Group	M_{Diff}	*SD*	Mean Rank	Sum of Ranks	*U*	*Z*	*p*
Feeling	EG	0.60	0.31	46.39	1623.50	161.50	-5.19	.001
	CG	0.13	0.27	21.89	722.50			
Value	EG	0.65	0.29	47.91	1677.00	108.00	-5.84	.001
	CG	0.09	0.30	20.27	669.00			
Re-engagement	EG	0.62	0.24	47.40	1659.00	126.00	-5.63	.001
	CG	0.18	0.25	20.82	687.00			
Knowledge	EG	0.82	0.36	46.31	1621.00	164.00	-5.15	.001
	CG	0.25	0.39	21.97	725.00			

Note: M_{Diff} = mean difference (posttest – pretest)

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Chemistry Motivation

At the beginning of the treatment, there was no statistically significant difference observed in the pretest scores between the EG and CG ($p > .05$). To assess the effect of the treatment between the two groups, gain scores were computed. As shown in Table 2, the results of the Mann-Whitney *U* test revealed significant differences between the EG and the CG across all motivational dimensions. The EG, which learned about electrolysis using IVR, demonstrated higher mean rank scores and mean differences between posttest and pretest compared to the CG, which used traditional multimedia-based teaching. In terms of intrinsic motivation, the EG showed a higher mean difference ($M = 0.38$, $SD = 0.34$) than the CG ($M = 0.16$, $SD = 0.68$), with a statistically significant difference ($U = 415.00$, $Z = -2.03$, $p = .043$). This finding indicates that IVR learning fostered a deeper internal drive to engage with chemistry learning compared to traditional multimedia. Similarly, for career motivation, the EG achieved a mean difference of 0.43 ($SD = 0.43$), surpassing that of the CG ($M = 0.13$, $SD = 0.72$). The difference was statistically significant ($U = 393.50$, $Z = -2.28$, $p = .022$), suggesting that VR-based experiences may enhance students' perception of chemistry as relevant to their future careers. The most notable result emerged in the self-determination dimension, where the EG recorded a substantially higher mean difference ($M = 0.80$, $SD = 0.50$) compared to the CG ($M = 0.10$, $SD = 0.79$). The statistical test confirmed a highly significant difference ($U = 264.50$, $Z = -3.86$, $p < .001$), indicating that immersive VR environments may effectively support students' sense of autonomy and control over their learning process. Regarding self-efficacy, the EG demonstrated a higher mean difference ($M = 0.58$, $SD = 0.47$) than the CG ($M = 0.18$, $SD = 0.82$), with the difference reaching statistical significance ($U = 370.00$, $Z = -2.56$, $p = .010$). This suggests that IVR learning enhanced students' confidence in their ability to perform chemistry-related tasks. For grade motivation, the EG achieved a mean difference of 0.43 ($SD = 0.34$), compared to 0.12 ($SD = 0.73$) in the CG, with the *U* test showing a significant difference ($U = 389.50$, $Z = -2.33$, $p = .020$).

Table 2
Difference (Gain Scores) in Motivation for the Two Groups

Dimensions	Group	M_{Diff}	*SD*	Mean Rank	Sum of Ranks	*U*	*Z*	*p*
Intrinsic motivation	EG	0.38	0.34	39.14	1370.00	415.00	-2.03	.043
	CG	0.16	0.68	29.58	976.00			
Career motivation	EG	0.43	0.43	39.76	1391.50	393.50	-2.28	.022
	CG	0.13	0.72	28.92	954.50			
Self-determination	EG	0.80	0.50	43.44	1520.50	264.50	-3.86	.001
	CG	0.10	0.79	25.02	825.50			
Self-efficacy	EG	0.58	0.47	40.43	1415.00	370.00	-2.56	.010
	CG	0.18	0.82	28.21	931.00			
Grade motivation	EG	0.43	0.34	39.87	1395.50	389.50	-2.33	.020
	CG	0.11	0.90	28.80	950.50			

Note: M_{Diff} = mean difference (posttest – pretest)

Discussion

This quasi-experimental study explored the effect of IVR in enhancing students' interest and motivation in chemistry among 68 Indonesian twelfth-grade students. Regarding RQ1, the findings revealed that students who engaged with chemistry content through IVR exhibited significantly higher levels of interest across all measured subscale dimensions compared to those in the comparison group. The results suggest that immersive technology can foster greater engagement with chemistry learning than conventional teaching methods. Consistent with previous research, IVR-based environments tend to evoke stronger affective responses and promote motivation through their interactive and immersive characteristics (Cheng & Tsai, 2020; Liu et al., 2022). These findings emphasise the pedagogical potential of VR as an innovative tool capable of capturing

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students' attention, maintaining involvement, and facilitating connections with scientific concepts. From a constructivist standpoint, virtual laboratories enable students to develop conceptual understanding through active experimentation and interaction with virtual elements, thereby stimulating deeper understanding and interest in chemistry (Chen et al., 2025; Cheng et al., 2023).

The current findings correspond with earlier studies showing that immersive VR learning can significantly increase students' interest (Andersen et al., 2023; Berkmen et al., 2025; Korlat et al., 2024). For example, Makransky et al. (2020) demonstrated that students participating in IVR-based science laboratory simulations experienced greater gains in interest from pretest to posttest than those receiving video-based teaching. Likewise, Gungor et al. (2022) found that VR-based activities enhanced undergraduate students' interest, self-efficacy, and self-concept, while simultaneously reducing their anxiety towards laboratory work.

As mentioned by Krapp et al. (1992), interest encompasses both situational interest and personal interest. Personal interest represents long-term preference and commitment, whereas situational interest arises from immediate emotional engagement triggered by environmental stimuli (Krapp et al., 1992). The sensory immersion, interactivity, and 3D manipulation in VR environments create optimal conditions for eliciting situational interest (Xiao & Hu, 2025). More broadly, immersive learning not only evokes interest but also elevates engagement, self-efficacy, and learning performance (Chen et al., 2025; Gungor et al., 2022). This is due to the fact that situational interest and learning exist in a reciprocal relationship, where the development of interest enhances knowledge acquisition and the resulting knowledge further strengthens that interest (Chen et al., 2025). In this study, the IVR-based learning embodied these principles by enabling students to explore, predict, and reflect on chemical phenomena, making the learning process more engaging and stimulating.

These findings align with empirical evidence that immersive technologies can substantially elevate situational interest, engagement, and performance among learners. For example, Sun et al. (2023) reported that VR applications in physics laboratories improved students' situational interest and engagement. Recently, Liu et al. (2025) observed that VR technologies enhanced students' enjoyment. Likewise, Mayer et al. (2023) emphasised that the educational impact of VR depends on its alignment with sound instructional design. The VR environment, characterised by its immersive and interactive features, offers learners vivid, first-hand experiences that create a novel and personally engaging context, thereby increasing their sense of presence and stimulating interest (Cheng et al., 2023; Christopoulos et al., 2023; Huang et al., 2023; Liu et al., 2022). In this research, the use of interactive chemical simulations and individualised exploration likely fostered greater situational interest and affective involvement among students. As Hidi and Renninger (2006) argued, when learning experiences are enjoyable and personally meaningful, students engage more deeply and persistently. Through its imaginative affordances, bridging emotional and cognitive engagement, VR-based learning can make chemistry education not only more stimulating but also more meaningful and enduring for students.

Addressing RQ2, this study compared students' learning motivation in IVR-based and traditional multimedia-based chemistry lessons. The results indicated that students exposed to the IVR environment demonstrated significantly higher motivation, reflecting positive perceptions of VR as a promising learning tool. The immersive and interactive features of VR appeared to enhance students' focus and participation in their learning processes, thereby effectively supporting motivation (Chang, 2024; Sun et al., 2023; Xiao & Hu, 2025). By promoting hands-on experiences and multisensory engagement, VR fosters students' stronger desire to learn chemistry, which in turn increases their learning motivation and satisfaction (Christopoulos et al., 2023; Jong, 2023). However, only the self-determination subscale reached a high level of statistical significance, while intrinsic motivation was marginally significant ($p = .043$). Although IVR appears to be a promising tool for science education, it should not be regarded as a panacea capable of addressing all challenges.

This result aligns with previous studies reporting that VR environments can strengthen students' motivation (Astatke et al., 2024; Aufenanger et al., 2025; Christopoulos et al., 2023; Laubscher et al., 2024). Liu et al. (2022), for instance, developed immersive science lessons for elementary students and demonstrated that IVR-based learning enhanced both academic performance and science motivation. Students in the IVR group also reported more positive and engaging learning experiences. Similarly, Yang et al. (2024) integrated Spherical Video-based Virtual Reality (SVVR) into an exploration-oriented model that improved students' motivation, attitudes, and creative thinking in chemistry. Li et al. (2025) further showed that VR educational games enabled middle school students to achieve deeper conceptual understanding and higher intrinsic motivation than those using conventional methods.

The motivational benefits of VR over conventional multimedia can be attributed to its combination of immersion, interactivity, and emotional engagement (Alrmuny & Ku, 2025; Liu et al., 2022). Unlike static two-

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dimensional videos, VR provides a sense of realism, thereby providing an experience that simultaneously stimulates visual and cognitive processing (Christopoulos et al., 2023; Liu et al., 2025). Such immersive features maintain students' long-term interest and engagement in science compared to video-based learning (Liu et al., 2025; Sun et al., 2023). The heightened realism and presence also foster curiosity and enjoyment, which in turn increase motivation and satisfaction (Laubscher et al., 2024; Xie et al., 2023). Consistent with existing studies (Aufenanger et al., 2025; Xiao & Hu, 2025), the present study confirmed that integrating IVR into the teaching and learning process enhanced engagement and participation by contextualising content and allowing meaningful interaction, ultimately increasing students' motivation and willingness to complete learning tasks (Korlat et al., 2024; Liu et al., 2022).

Indonesia is particularly sensitive to the lack of engagement in scientific studies, with only 7% of 15-year-old students expressing a desire to pursue a career in science or technology (OECD, 2023). Without claiming that IVR is a magic solution, our results clearly show that IVR could contribute to science career motivation. These results are in line with previous research showing that the use of virtual environments can influence career aspirations in science (Makransky et al., 2020). The results of the present study can be further explained through Self-Determination Theory (Ryan & Deci, 2000), which posits autonomy, relatedness, and competence as the psychological foundations of intrinsic motivation. VR environments, by offering responsive interaction and positive experiences, fulfil these psychological needs, thereby strengthening students' intrinsic motivation (Laubscher et al., 2024). Empirical studies support this perspective (Liu et al., 2022; Özer & Şimşek, 2025), showing that IVR-based learning increases enjoyment and engagement relative to conventional approaches. The game-like, immersive nature of VR can stimulate curiosity and a sense of accomplishment, encouraging sustained effort and deeper learning (Liu et al., 2022; Sun et al., 2023). Accordingly, pedagogical approaches that integrate IVR can reshape students' motivational beliefs by fostering a more autonomous and engaging learning process, particularly in chemistry education, where abstract concepts and perceived difficulty often hinder students' meaningful learning experiences.

Conclusions and Implications

This study explored the effects of IVR applications on the affective dimensions of student engagement in the context of chemistry education. The findings reveal that integrating VR technology significantly enhances students' interest and motivation compared with conventional teaching approaches. It can be concluded that the use of IVR has a positive impact on twelfth-grade students' interest and motivation to learn chemistry. Grounded in constructivist learning theory, the findings highlight VR's capacity to transform traditional classrooms into dynamic, interactive environments where students construct knowledge through immersive and experiential participation. Consequently, IVR emerges as an effective pedagogical medium for visualising abstract chemical concepts while deepening students' conceptual understanding and affective engagement.

The present study underscores that immersive learning through VR benefits upper-secondary school students by stimulating greater interest and motivation towards chemistry. Beyond demonstrating VR's pedagogical effectiveness, this study contributes valuable insights into how immersive technologies can be effectively designed and implemented to address students' affective needs. Moreover, the findings serve as an essential reference for policymakers seeking evidence-based guidance in allocating resources for VR implementation in secondary schools, particularly in developing countries. Such investments can promote active learning, enhance conceptual understanding, and strengthen motivation among students. Finally, our study opens new directions for further inquiry into optimising IVR for educational purposes. Future studies may extend these investigations to other chemistry topics or across different scientific disciplines to examine the generalisability and long-term impact of immersive learning. These findings underscore VR's transformative role as both an instructional and motivational tool for advancing chemistry education at the upper-secondary school level.

Limitations and Future Studies

The study is not without limitations, which should be taken into account when interpreting the findings. First, the relatively small sample size of 68 participants may constrain the generalisability of the results. Future studies should involve larger and more diverse samples across different educational levels (primary schools and universities) and school types (public and private schools) to enhance external validity. Second, the potential novelty effect of using VR, which is still uncommon in secondary education, may have temporarily increased

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students' interest and motivation. Longitudinal studies with extended exposure and participants familiar with VR are needed to determine the sustainability of the observed effects. Moreover, the exclusive use of a quantitative design limits the depth of understanding of students' experiences. Future studies are encouraged to employ mixed-method designs, combining quantitative assessments with qualitative approaches such as focus group discussions and in-depth interviews, to capture the complex and multifaceted nature of learning engagement in immersive environments. Additionally, a single-session intervention focuses solely on short-term outcomes, underscoring the need for delayed and long-term assessments to determine whether interest and motivation evolve into enduring individual interests and motivations. Given that nearly three-quarters of the participants in the present study were female, future research is encouraged to involve more balanced gender compositions to more accurately capture potential gender-related variations in students' interest and motivation when learning chemistry through IVR. Finally, since the study relied solely on self-reported measures, the data may be subject to social desirability and response biases (Dodou & De Winter, 2014). Hence, incorporating behavioural observations in future studies would strengthen the accuracy and validity of findings on students' interest and motivation in VR learning environments.

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Declaration of Interest

The authors declare no competing interests.

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